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Epitaxial growth and characterization of 4H-SiC for detection applications

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Summary

Introduction
- SiC physical properties
- Epitaxial Growth

4H-SiC applications
- Particles detection

Characterization
- Photoluminescence maps
- Raman spectra
- Carrier Lifetime

Influence of the defects on carrier lifetime
- Study of Different types of SF defects

Conclusion

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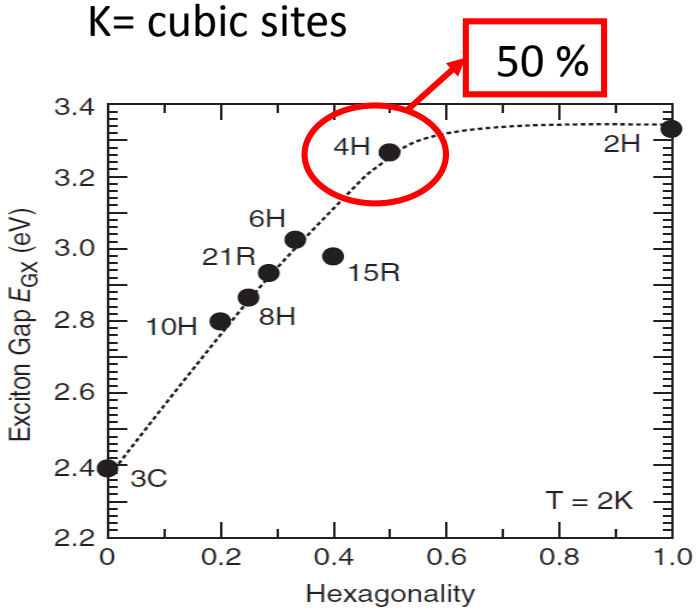
Introduction

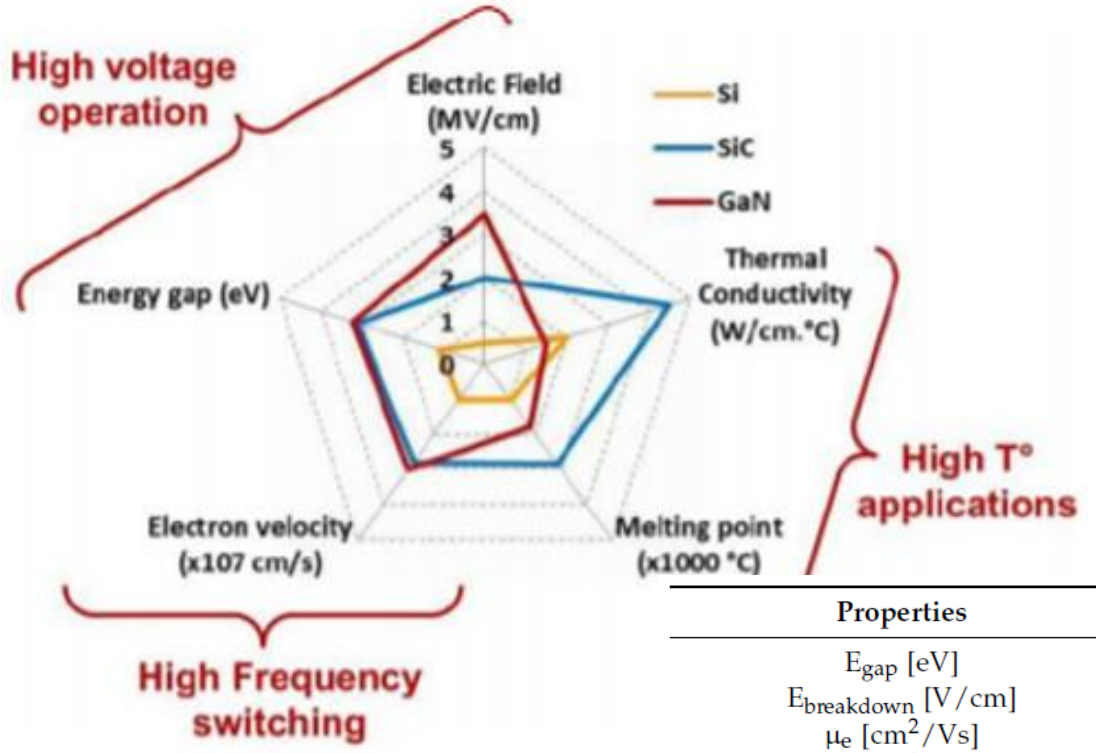
SiC physical properties

H(%)= $(h/h+k)*100$

h= hexagonal sites

K= cubic sites





Other properties

- Transparency to visible light
- Ultraviolet (UV) wavelength absorption
- Radiation hardness
- Biocompatibility…

Properties	4H–SiC	Si
E_{gap} [eV]	3.23	1.12
$E_{breakdown}$ [V/cm]	3–4 × 10^6	3 × 10^5
μ_e [cm^2/Vs]	800	1450
μ_h [cm^2/Vs]	115	450
$V_{saturation}$ [cm/s]	2 × 10^7	0.8 × 10^6
Z	14/6	14
ε_r	9.7	11.9
E–h energy [eV]	7.6–8.4	3.6
Density [g/cm^3]	3.22	2.33
Displacement *E* [eV]	30–40	13–15
Thermal Conductivity [W/cm·K]	4.9	1.5

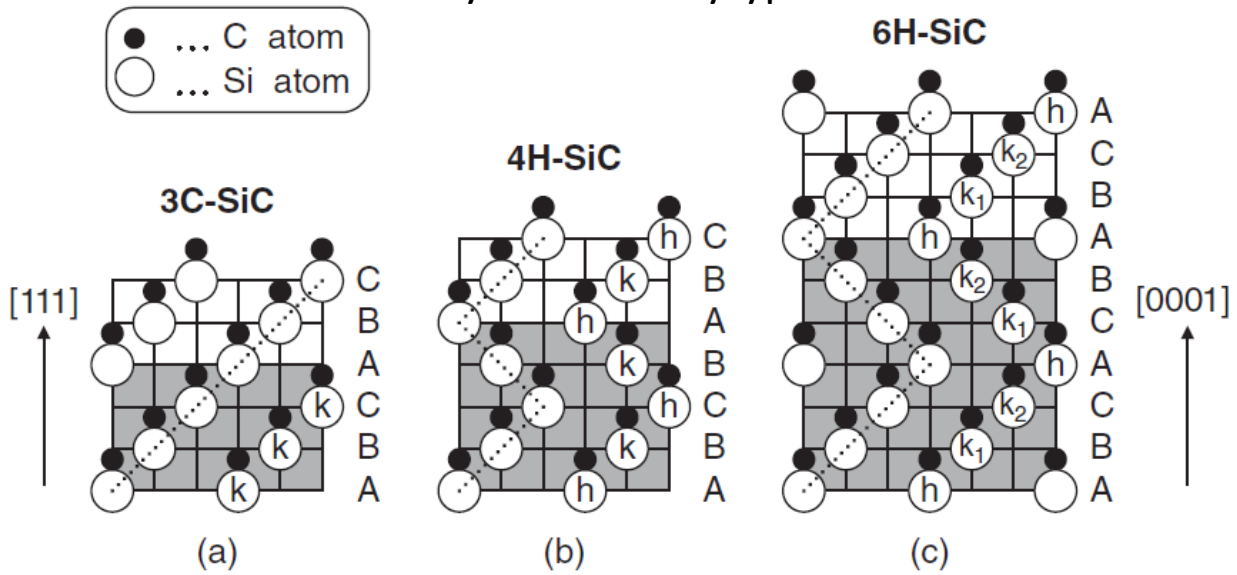
Introduction

SiC physical properties

$$Si, 14e^- : 1s^2 2s^2 2p^6 3s^2 3p^2$$

$$C, 6e^- : 1s^2 2s^2 2p^2$$

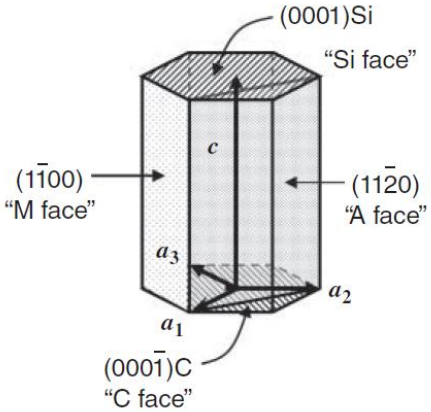
Cryistalline Polytypes



***Kimoto** et al., Silicon Carbide Epitaxy, edited by F. La Via (Research Signpost, 2012)*

Crystallographic characteristics of the SiC polytypes

Polytype	*Unit cell sequence*	*Lattice parameters (nm)*	*Inequivalent sites*	*Structure*	*Hexagonality rate (%)*
2H-SiC	AB	a=0.3081 c=0.5048	1	hexagonal (wurtzite)	100
3C-SiC	ABC	a=0.4349 a=0.3081c=0.75	1	cubic(zincblende) hexagonal (hcp)	0
4H-SiC	ABAC	a=0.3081 c=1.08	2	Hexagonal closed packed (hcp)	50
6H-SiC	ABCACB	a=0.3081c=1.501	3	hexagonal (hcp)	33
15R-SiC	ABCACBCABACABCB	a=0.3081 c=3.77	5	rhombohedral	40



Introduction

Epitaxial growth

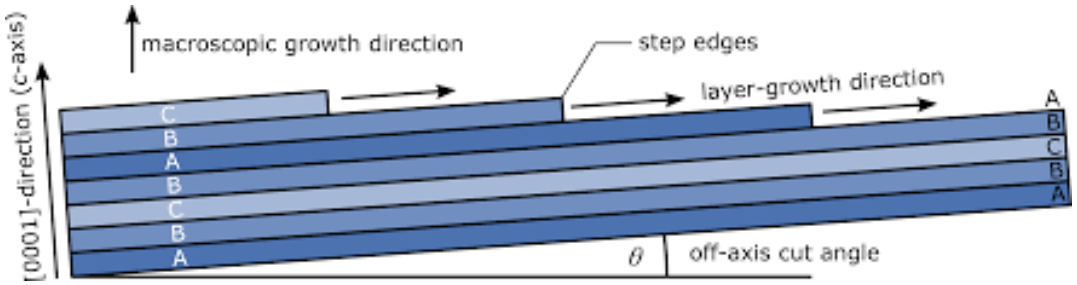
Horizontal hot-wall reactor

Substrate:

- 4H-SiC (0001)
- Si face
- n-type ($\cong 10^{18}$ cm^{-3})
- Off-axis ($\cong 4°$)

Parameters:

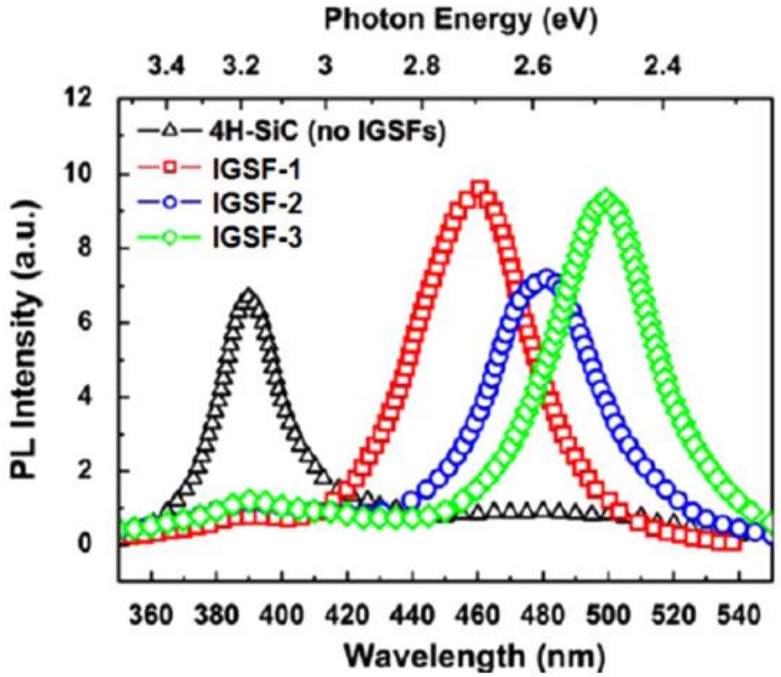
- Si/C
- T (1550-1650°C)
- Dopant gas control
- Hydrogen flow (150 slm)
- Cloride compounds
- Low pressure regime (100 mbar)



*Silicon Carbide Epitaxy, edited by **F. La Via** (Research Signpost, 2012)*

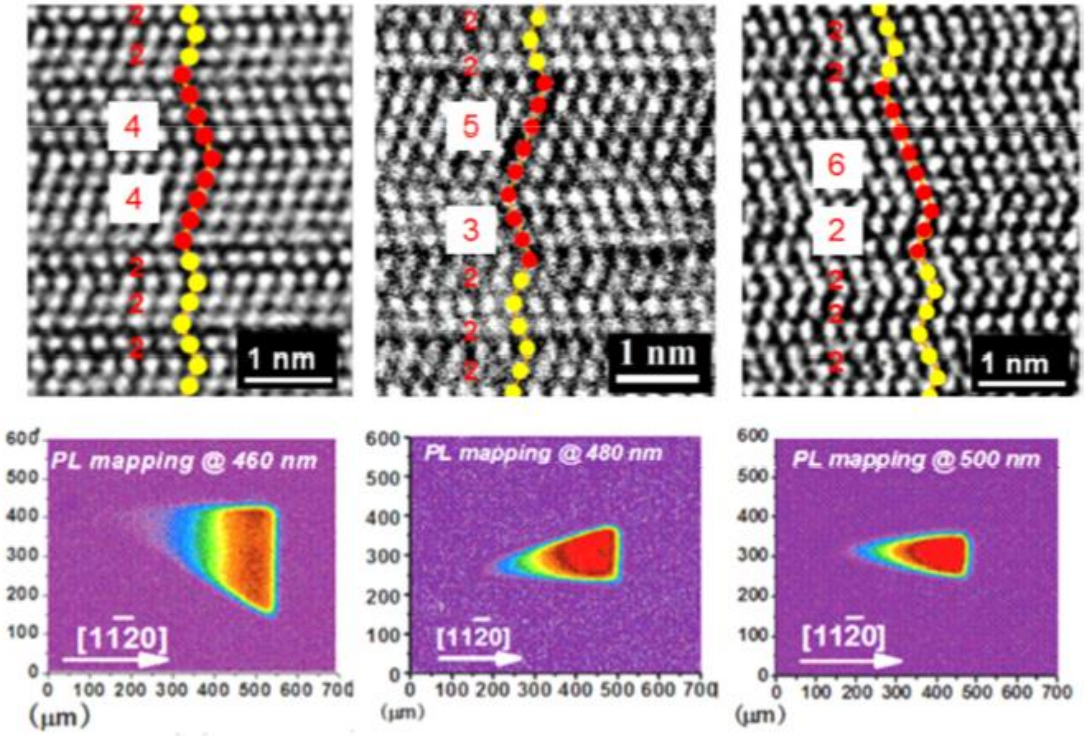
Introduction

Epitaxial growth



***Kimoto** et al., Silicon Carbide Epitaxy, edited by F. La Via (Research Signpost, 2012), Chap. 6.*

Stacking faults



***Kimoto** et al., Silicon Carbide Epitaxy, edited by F. La Via (Research Signpost, 2012)*

Killer defects ⟶

- Carrier lifetime
+ Leakage current

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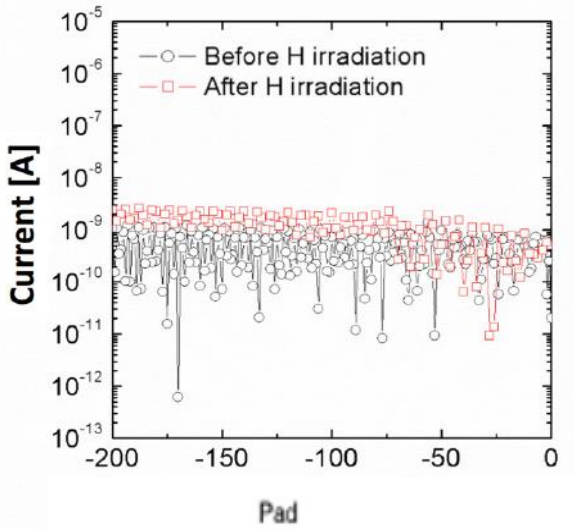
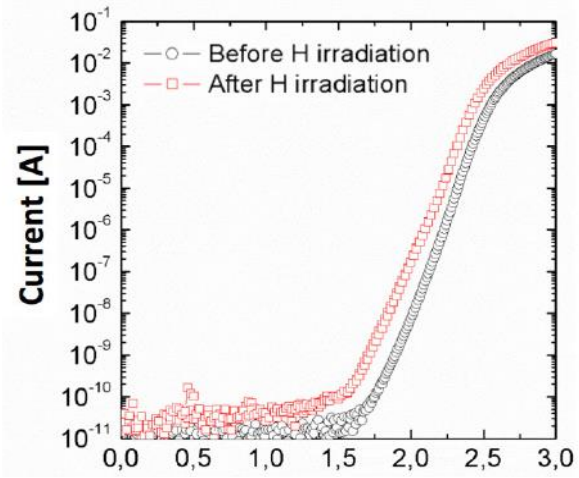
4H-SiC applications

Particles detection

Radiation Hardness





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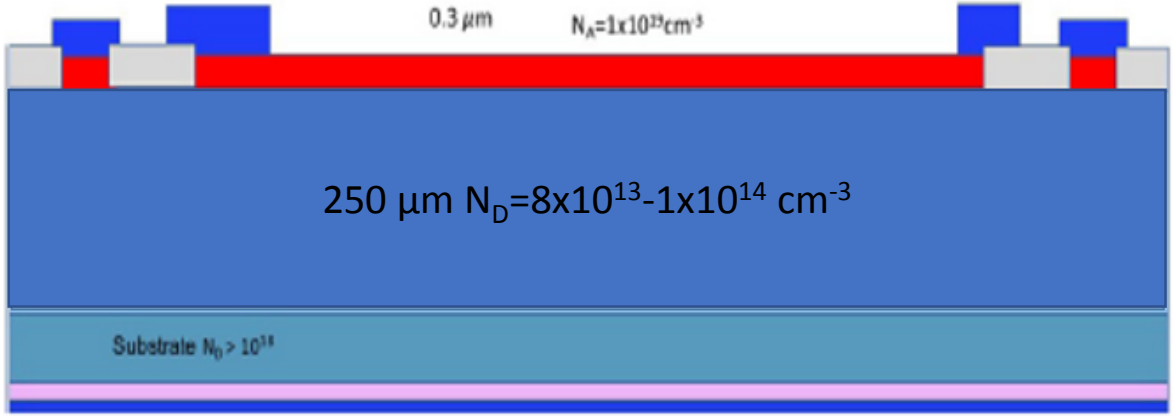

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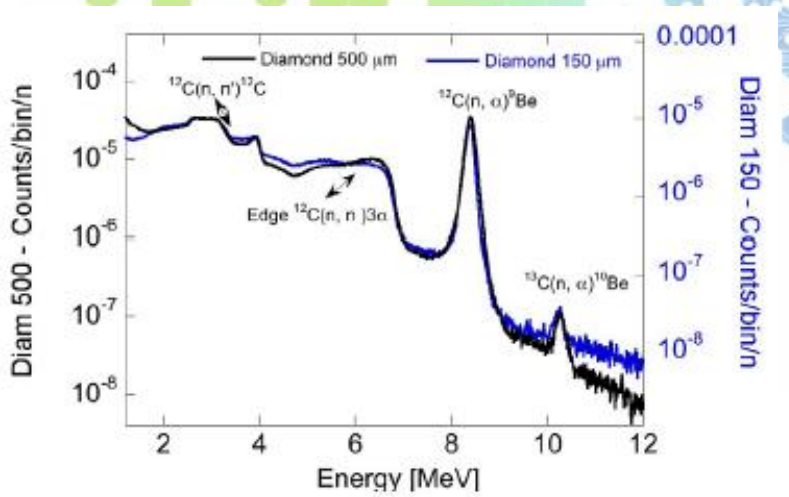
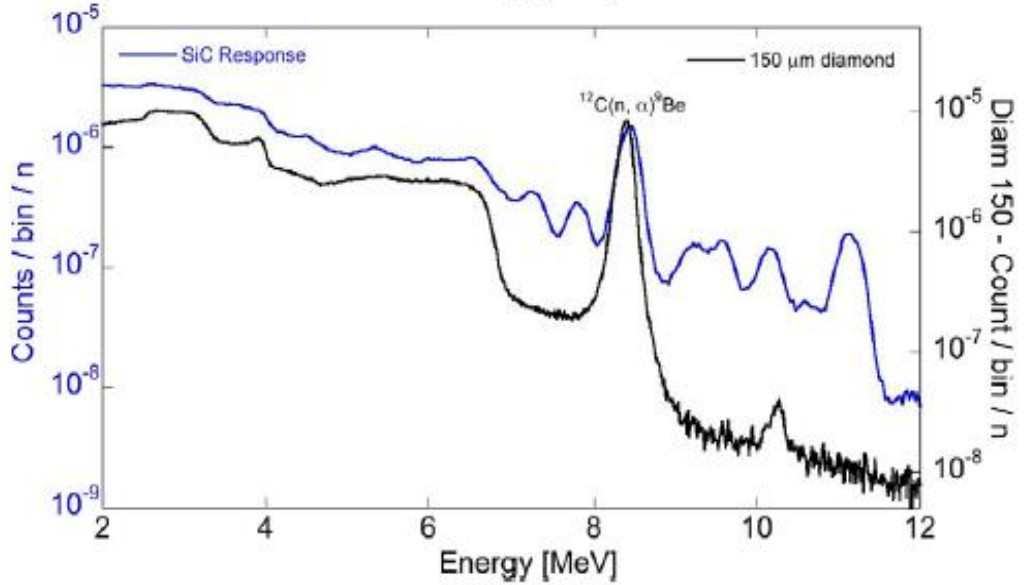
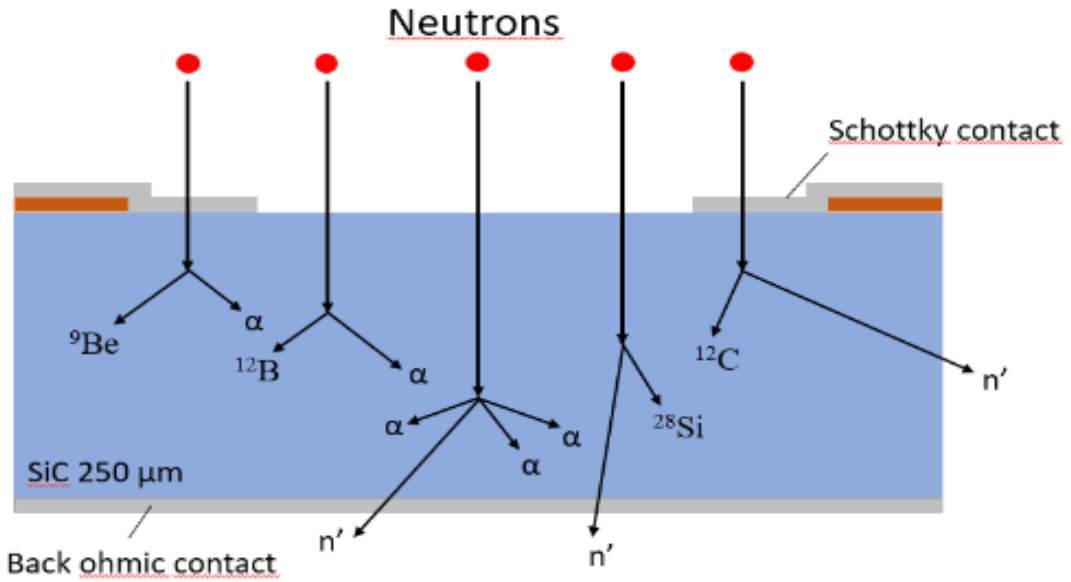


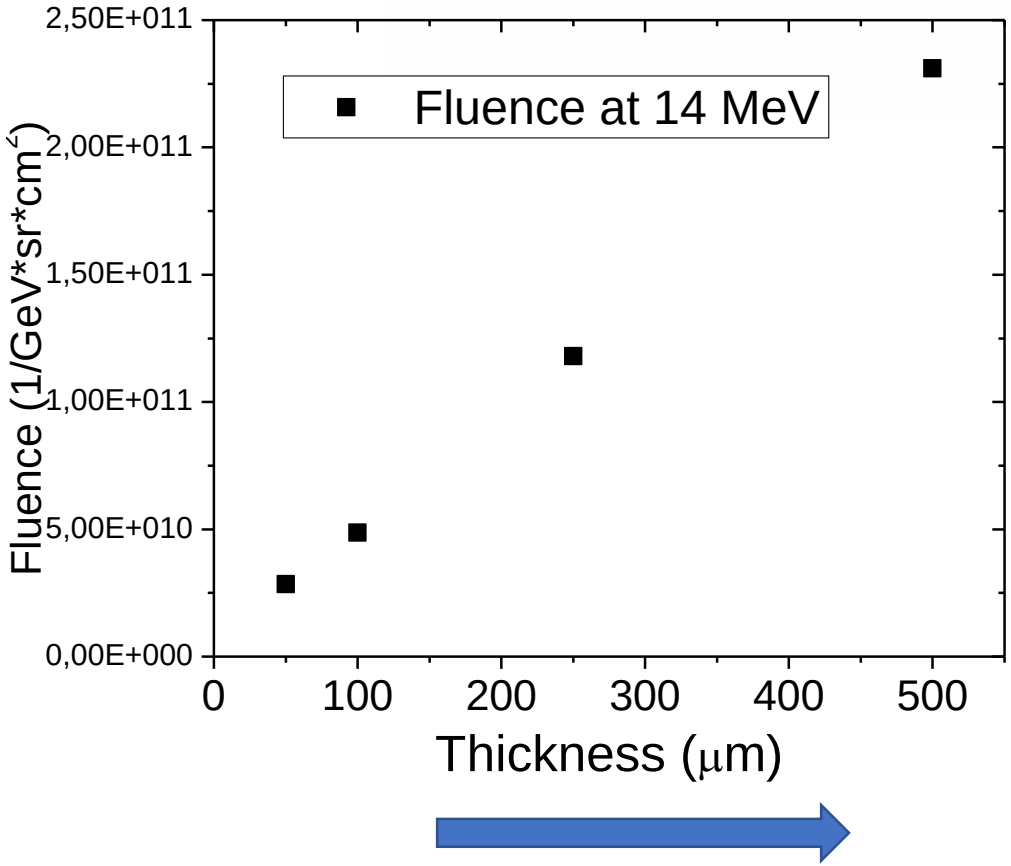


bai M. *et al., New thick silicon carbide detectors: Response to 14 MeV neutrons and nparison with single-crystal diamonds. Nucl. Instrum. Methods Phys. Res. Nuclear Inst. And thods in Physics Research, A 946 (2019) 162637.*

4H-SiC applications

Fluence calculation with Fluka





These reactions are triggered by interaction of 14 MeV fast-neutrons with Si and C nuclei.

Deuterium-tritium neutron generator.

Detectors yeald

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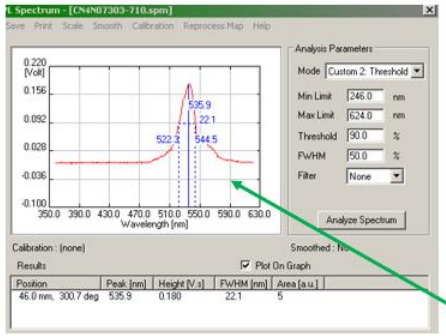
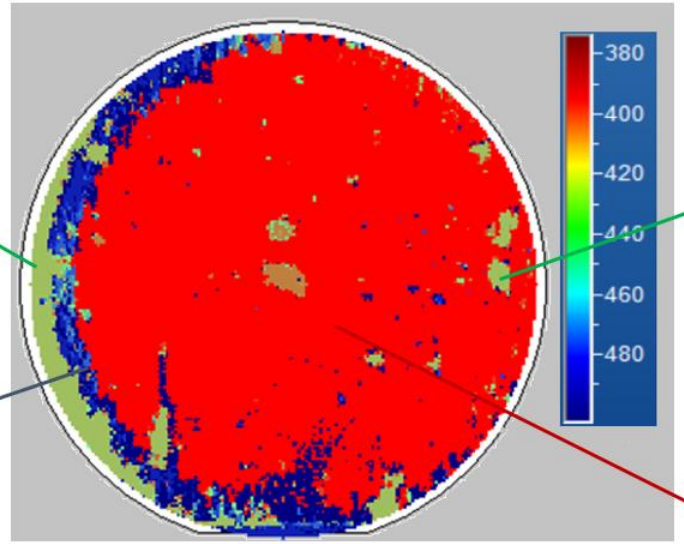
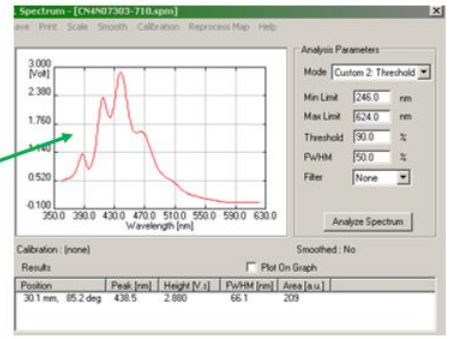
Photoluminescence maps

3C PL signal

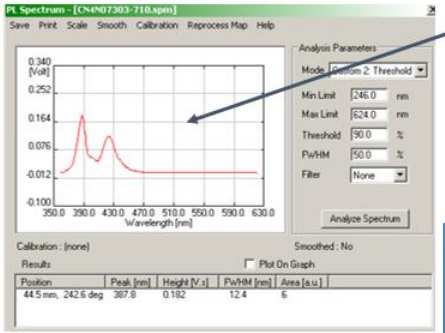




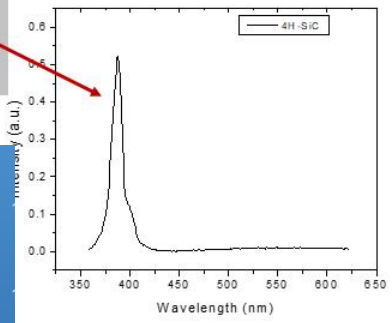
Additional PL signals

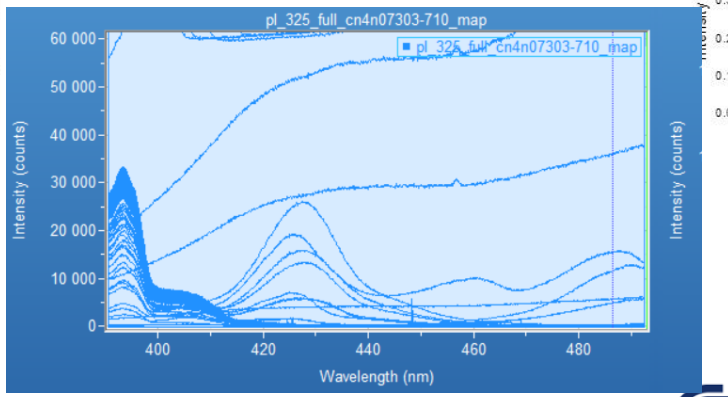


Additional PL signal @420nm

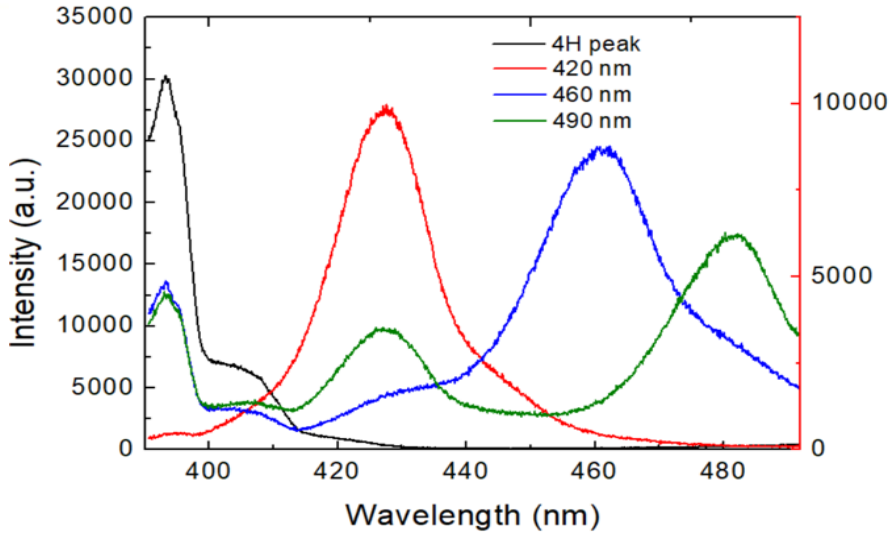


4H PL signal



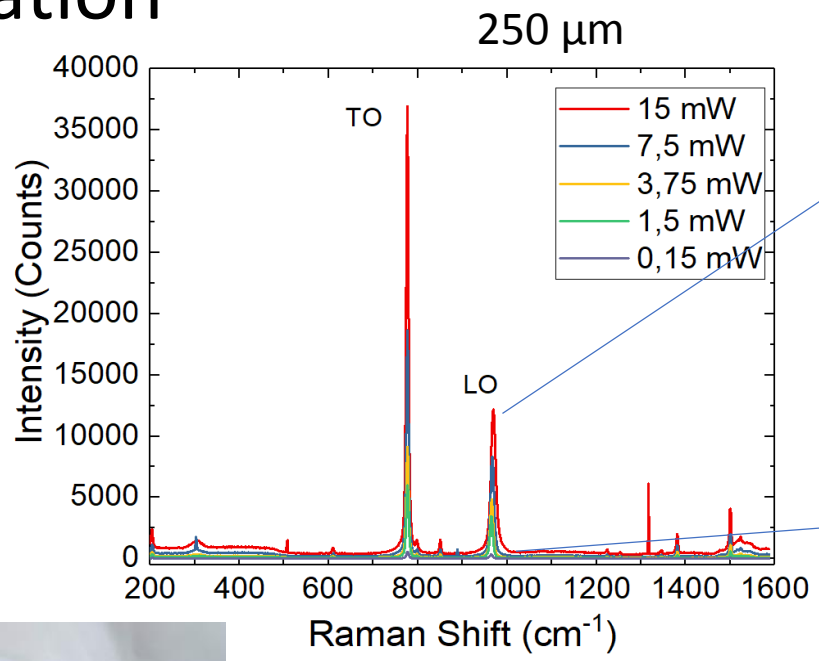


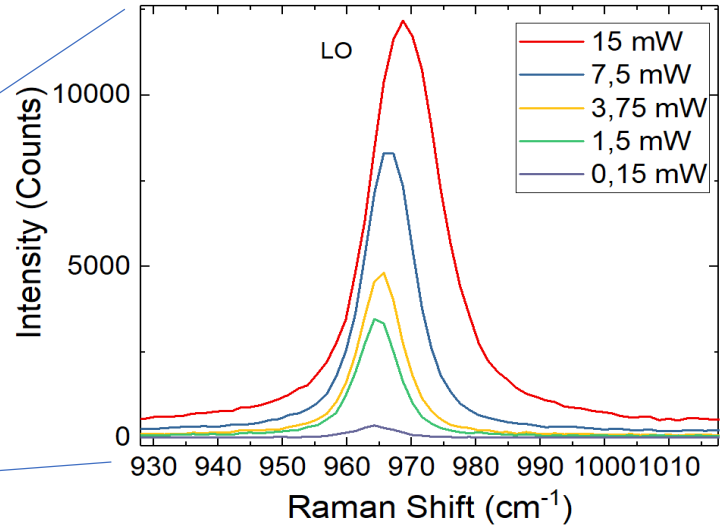
- 390 nm Band-to-band peak
- 430 nm bar shaped or SSF
- 460 nm SF (4,4)
- 490 nm SF (5,3)

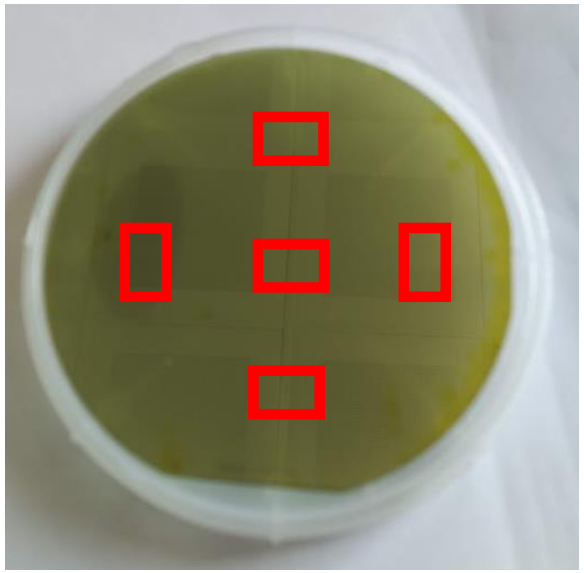


Characterization

Raman spectra







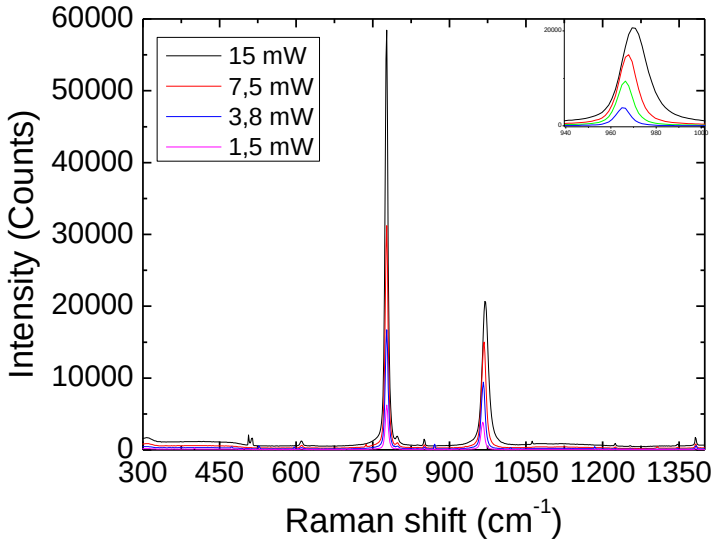
Laser Power increase

- Matrix: 5x2 and 4x4
- Laser: He-Cd 325nm
- Laser power: 15-7,5-3,8-1,5-0,15 mW
- Objective 40x
- Acquisition time= 12s
- Spot laser radius= 4,5 micron

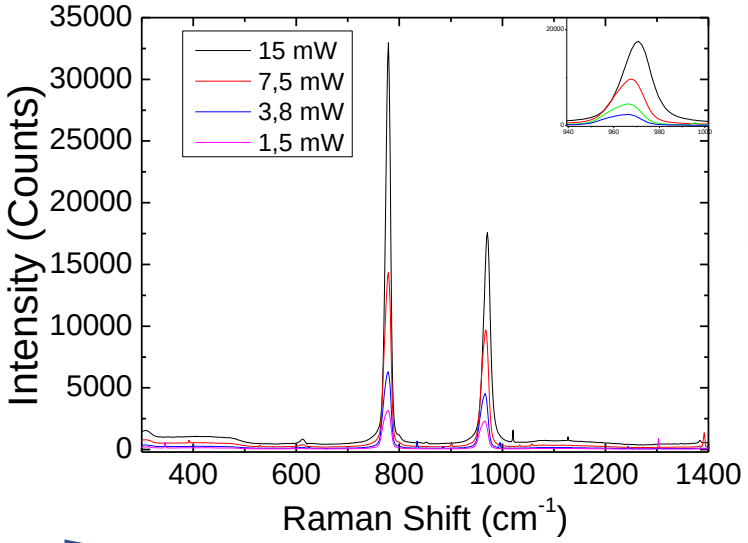
Characterization

Raman spectra

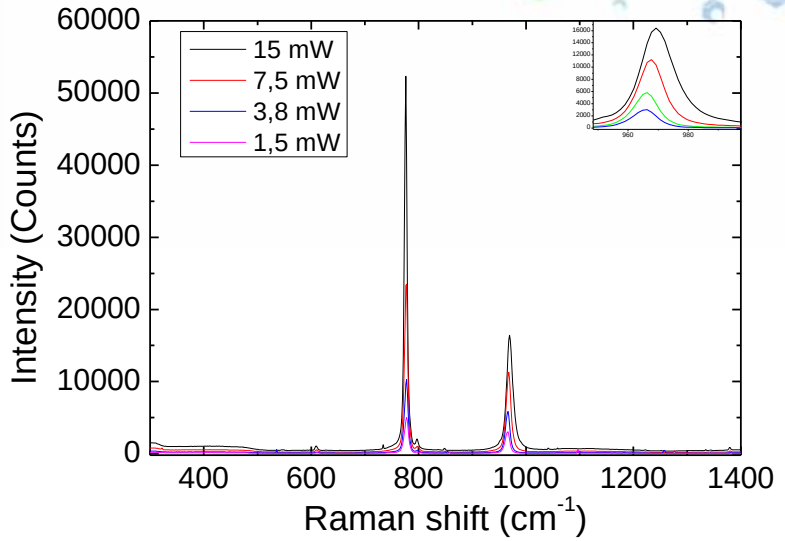
250 um



100 um_60 um/h



100 um_90 um/h



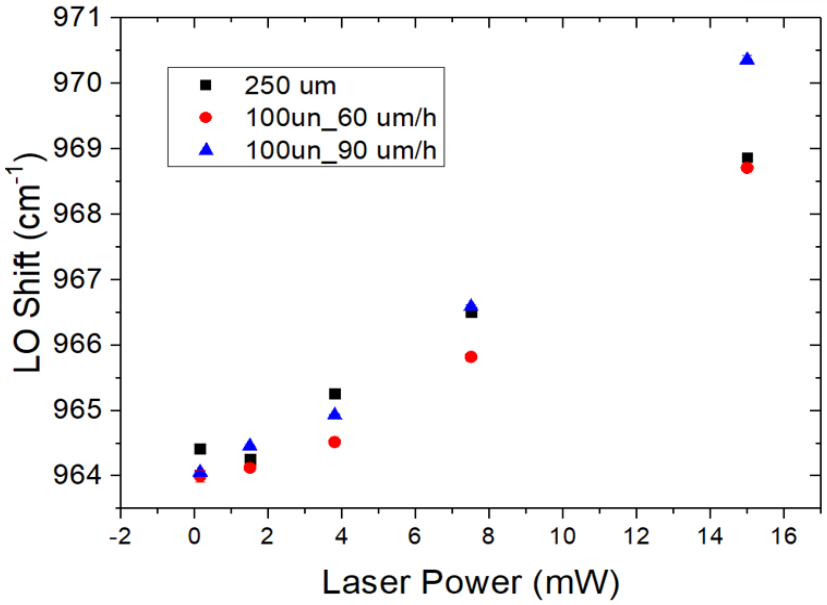
Laser Power increase

$$\omega_P^2 = \frac{4\pi n e^2}{\varepsilon_0 \varepsilon_\infty m^*} \longrightarrow \text{n}$$

$$\gamma_p = \frac{e}{m^* \mu} \longrightarrow \mu$$

$$G = \Phi \alpha e^{\alpha x}$$

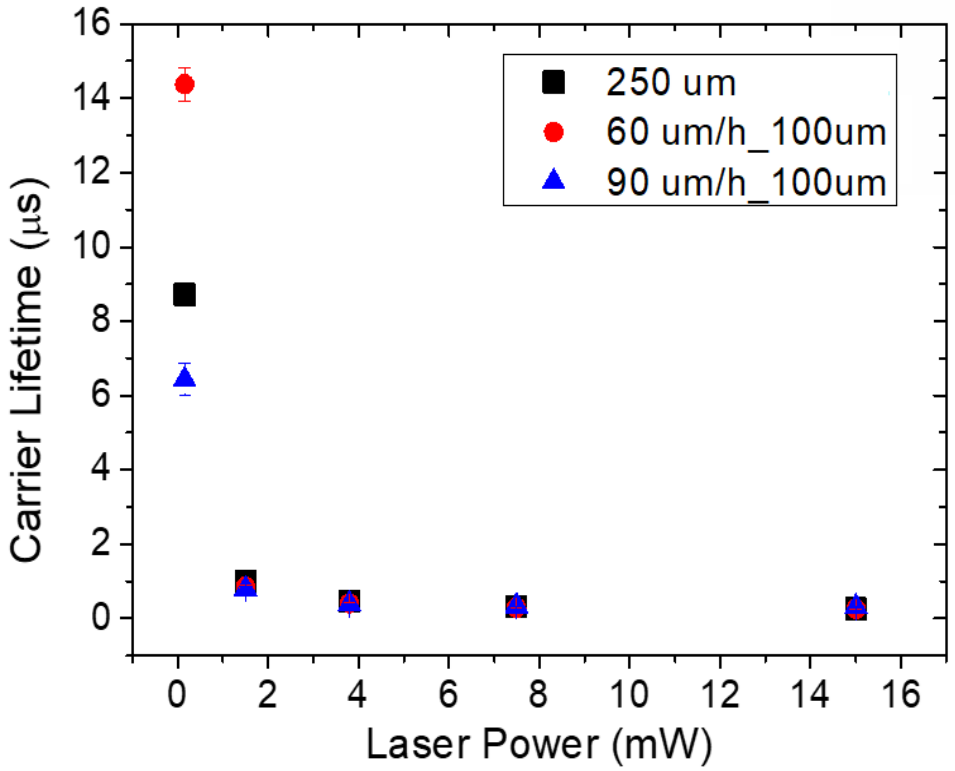
$$U = G = n - n_0/\tau,$$

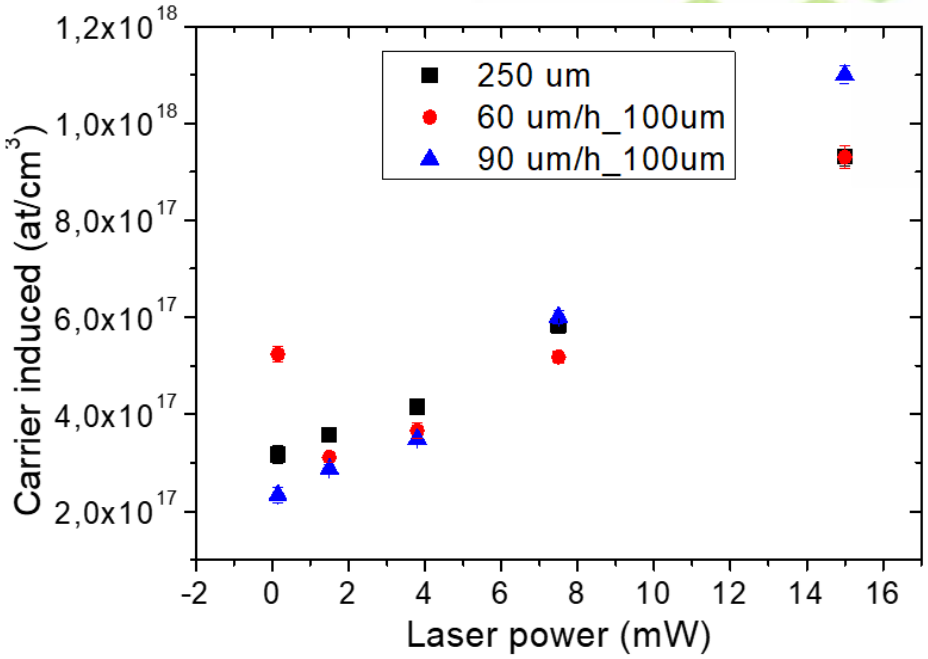


M. Chafai et al., J. Appl. Phys. 90, 5211 (2001).

Characterization

Carrier lifetime post PL





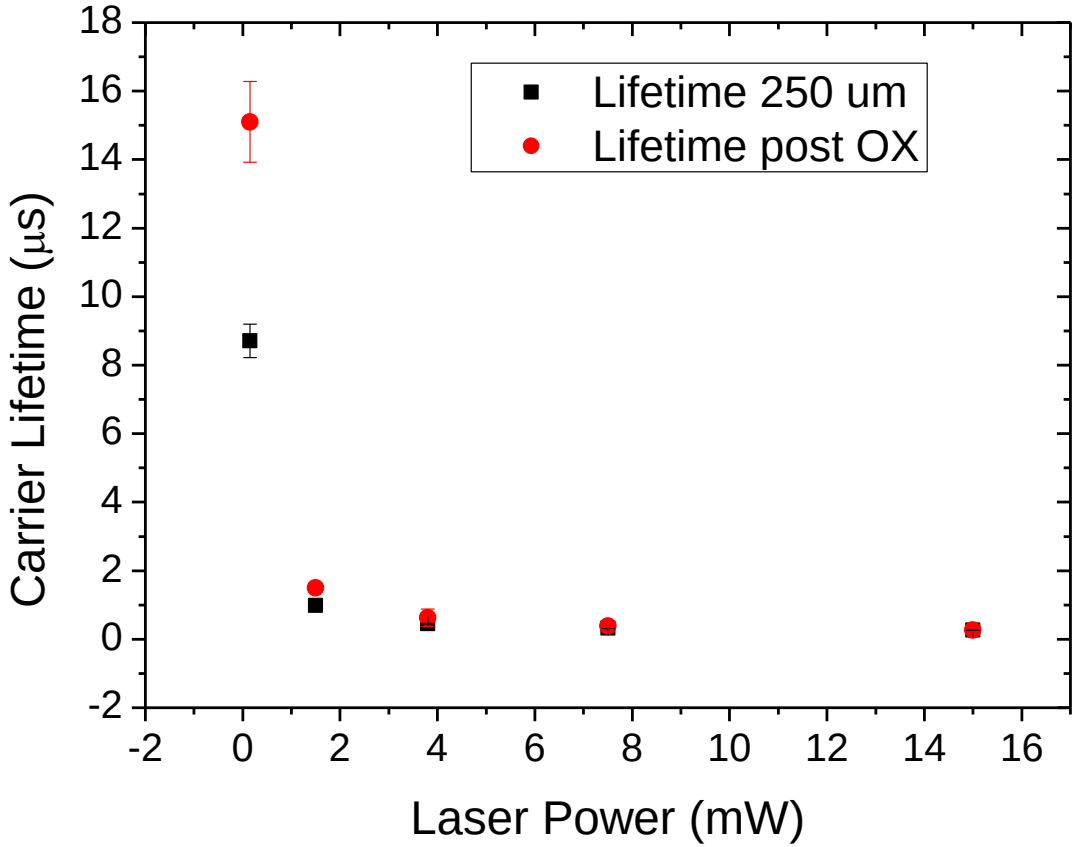
Auger recombination mechanism

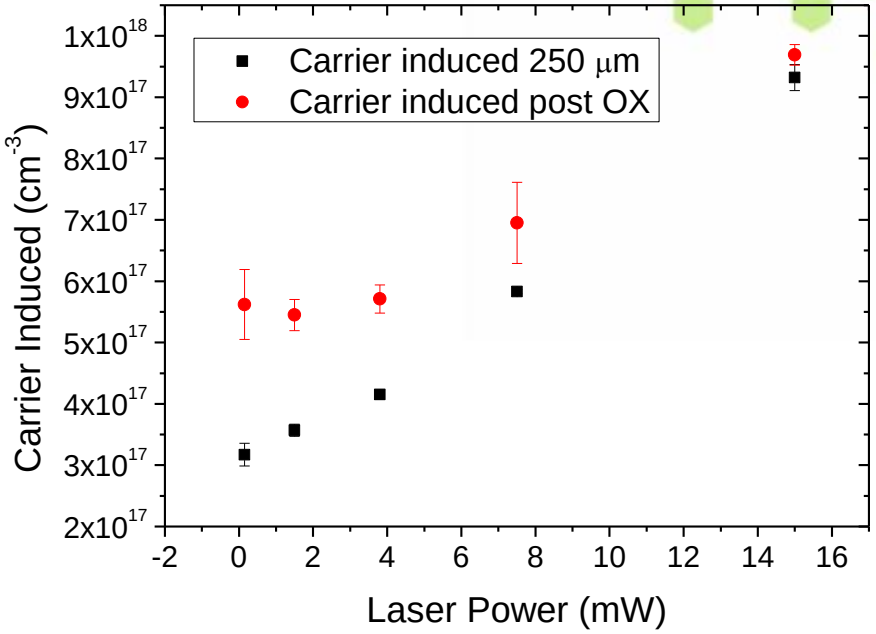
Potenza (mW)	250 µm τ (µs)_PL	60 µm/h τ (µs)_PL	90 µm/h τ (µs)_PL
0,15	8,71	14,38	6,43
1,5	0,98	0,85	0,80
3,8	0,45	0,40	0,38
7,5	0,32	0,28	0,33
15	0,26	0,25	0,30

Oxidation process

Carrier lifetime

- 1400°C - 48h





Potenza (mW)	*250 µm τ (µs)_No Ox*	*250 µm τ (µs)_postOX*
0,15	8,71	15,10
1,5	0,98	1,50
3,8	0,45	0,63
7,5	0,32	0,38
15	0,26	0,27

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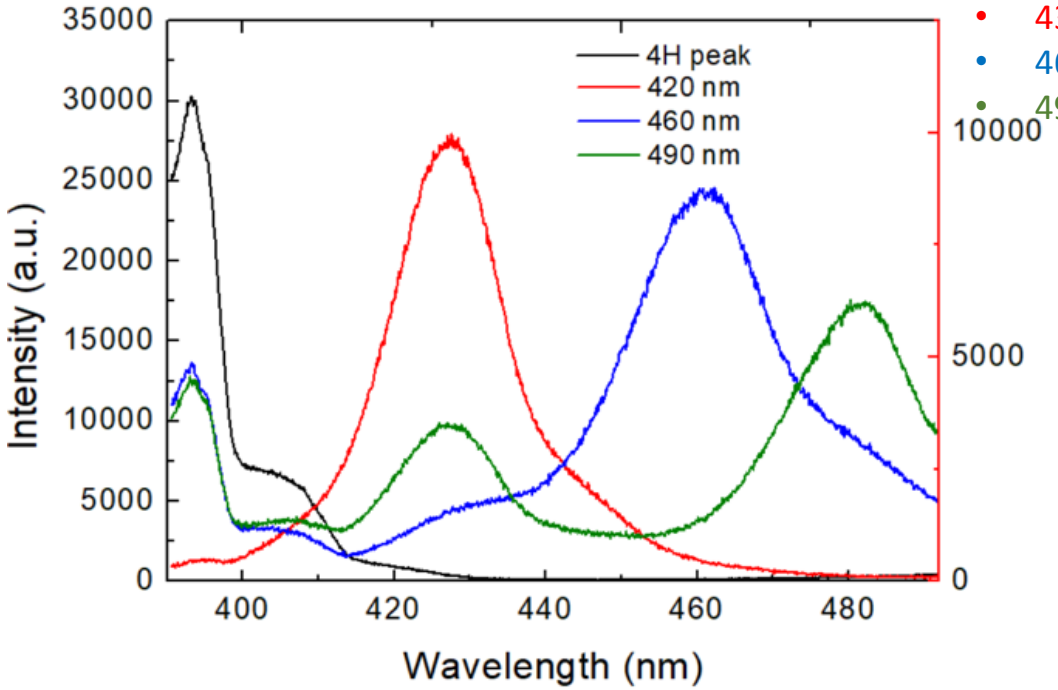
Defect Study

Influence on carrier lifetime



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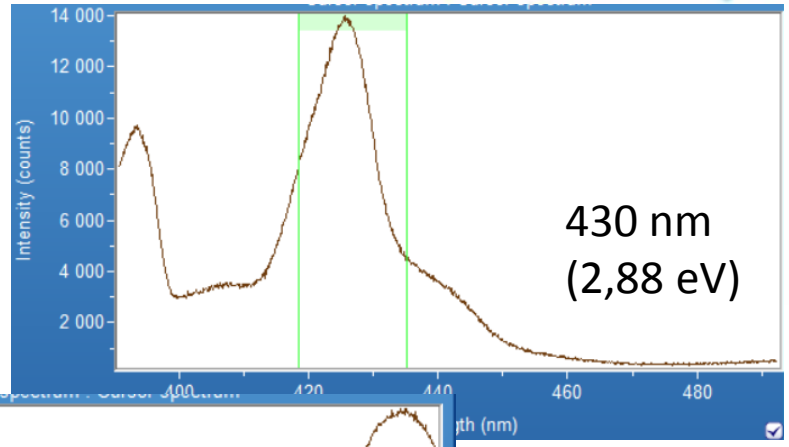
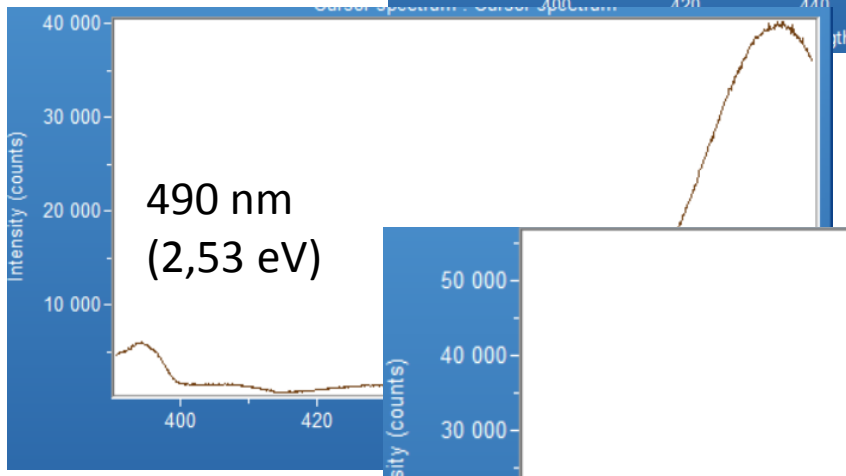
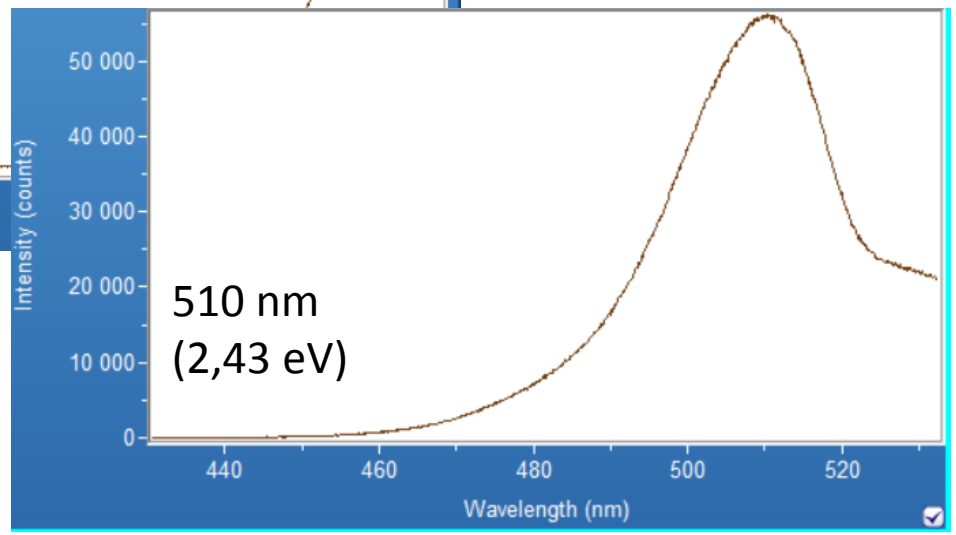
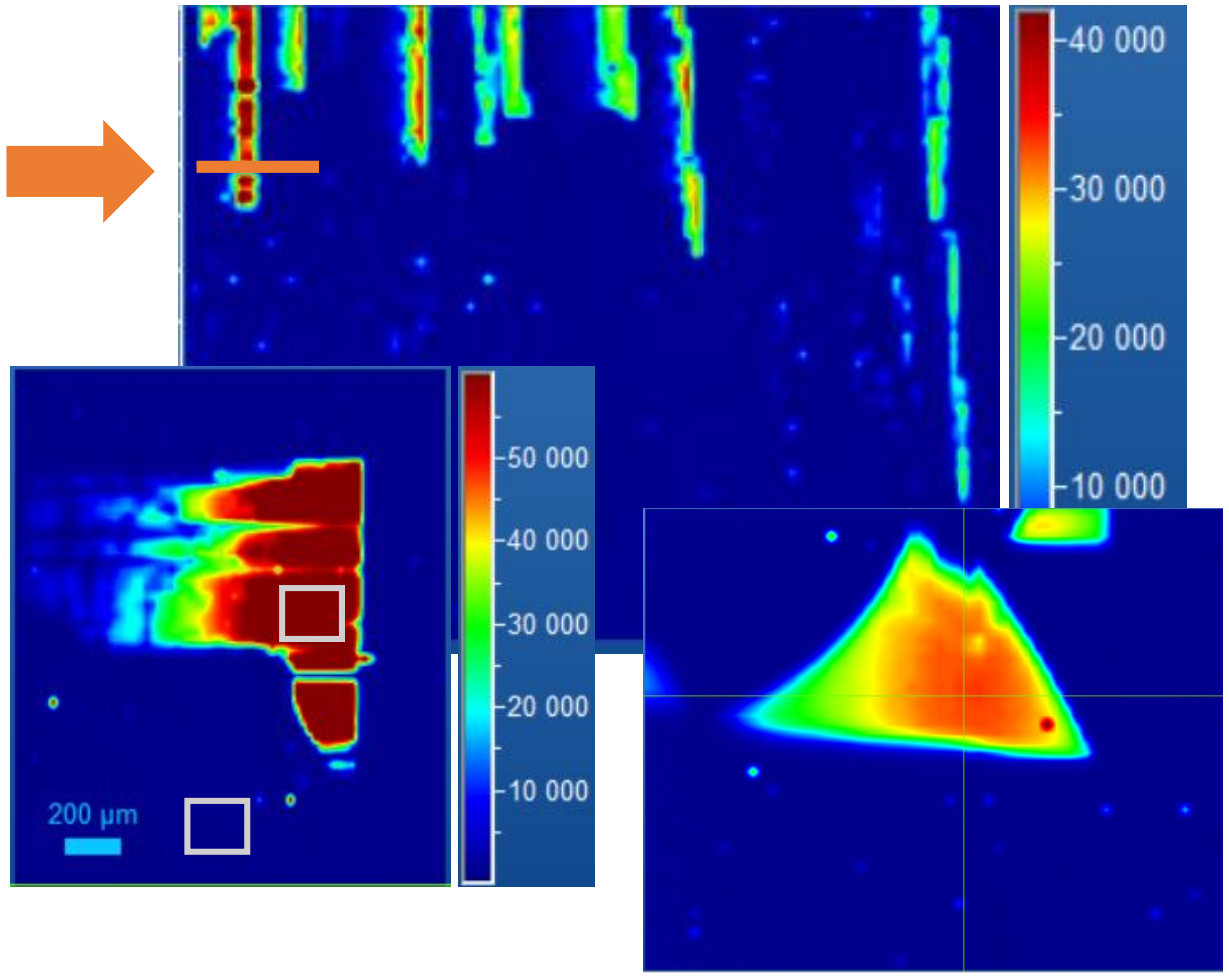


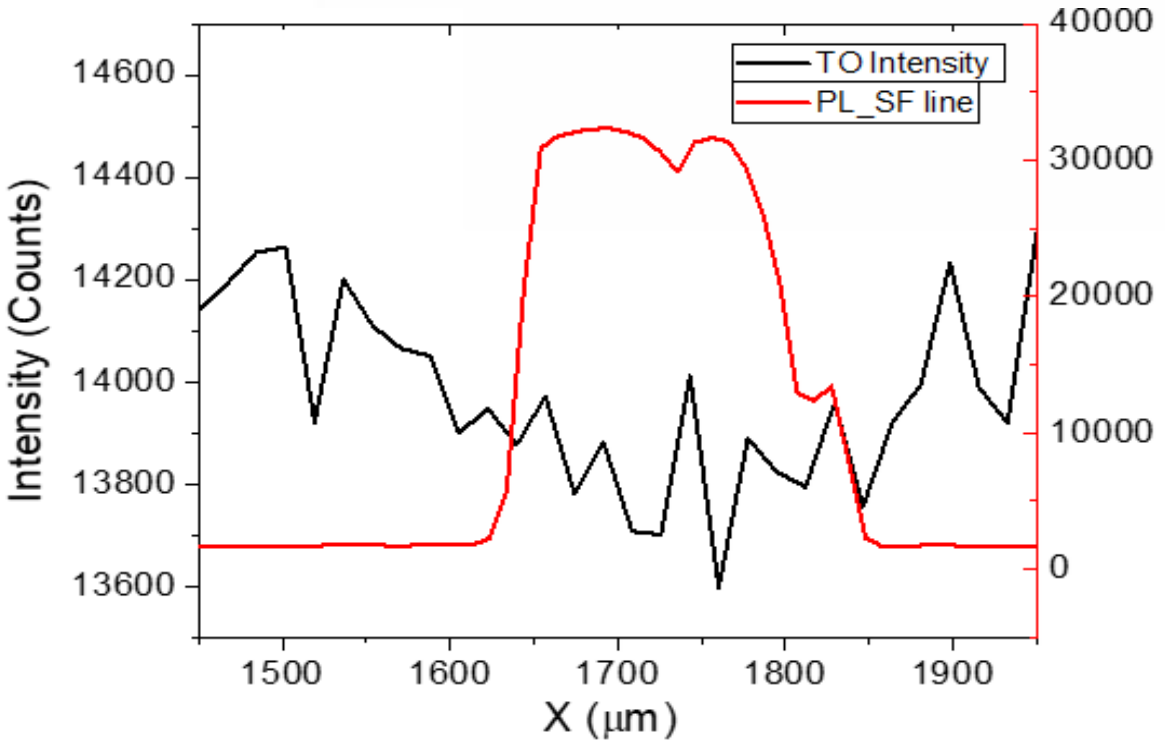




Defect Study

430 nm (2,88 eV)





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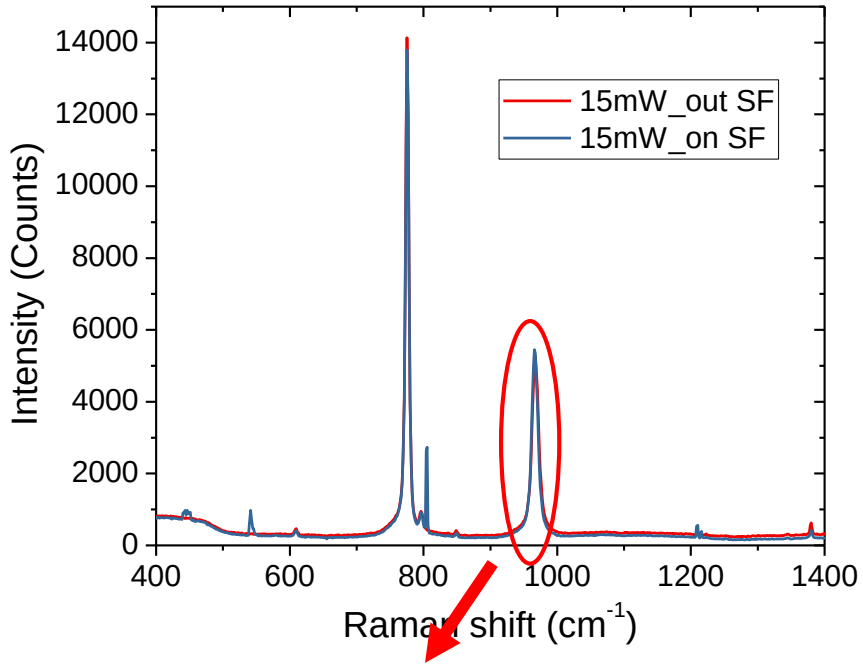
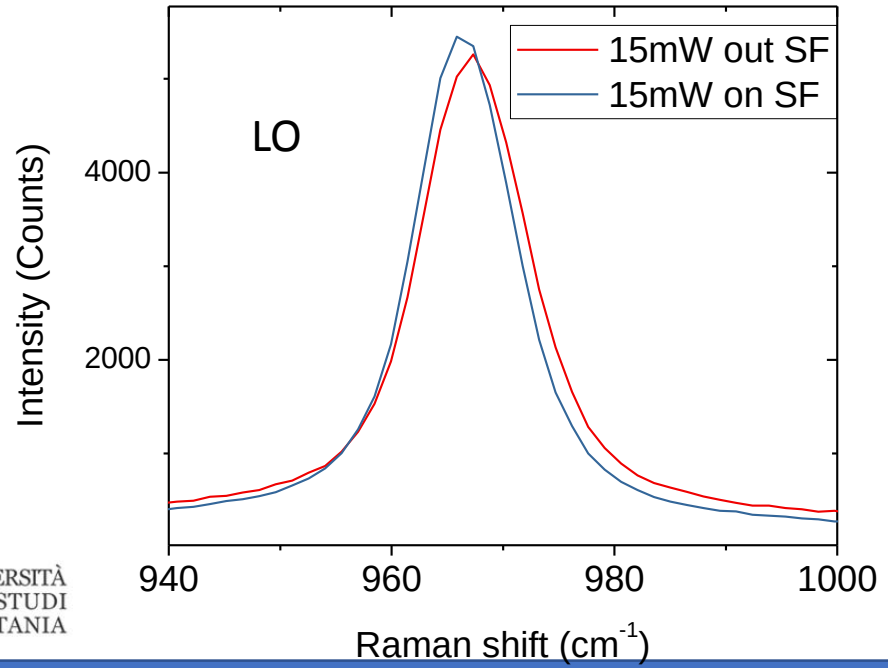
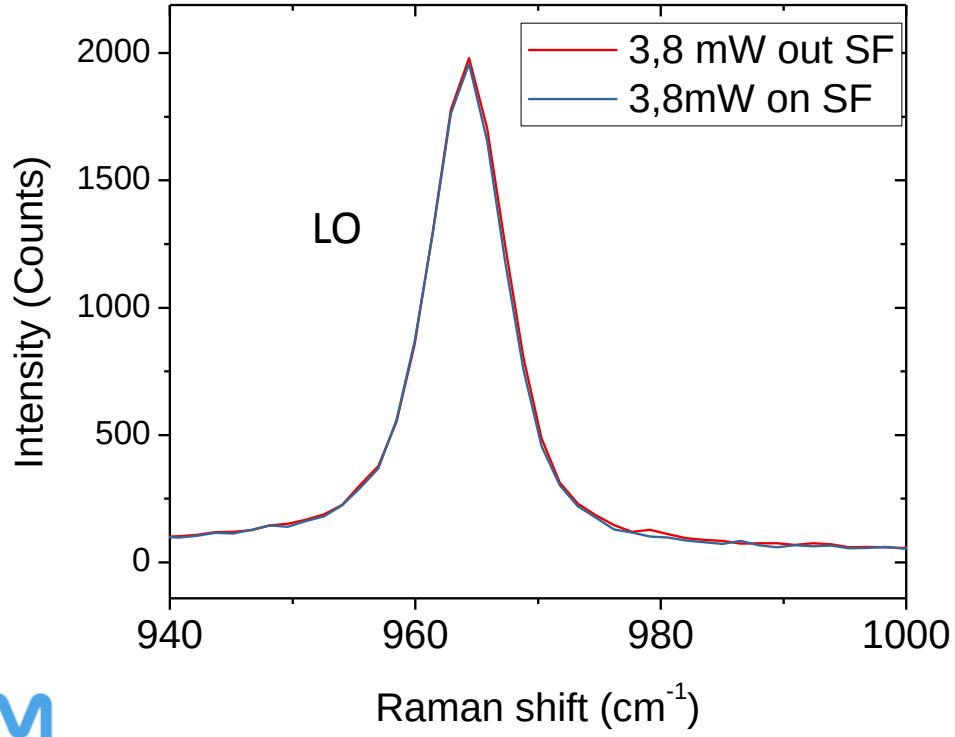






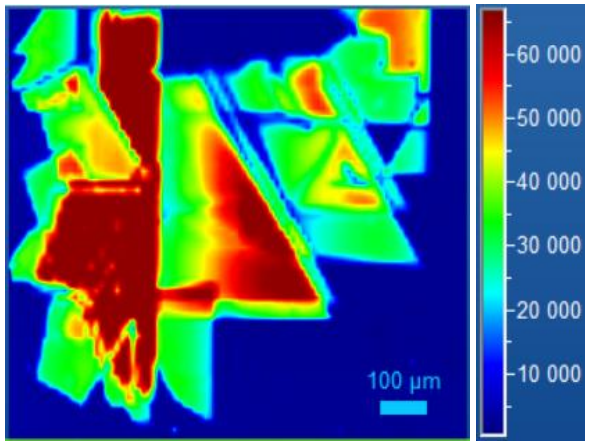
Defect Study

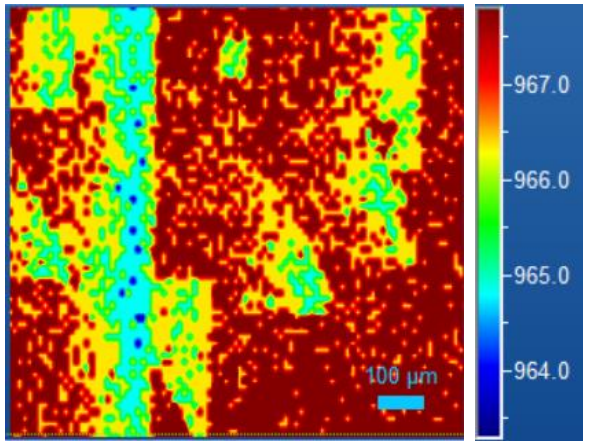
430 nm isolated

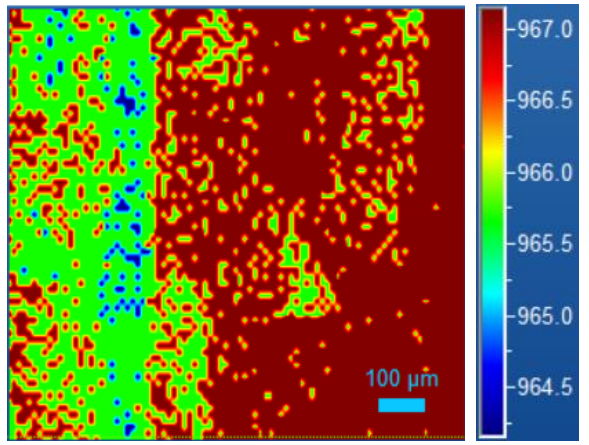
15 mW

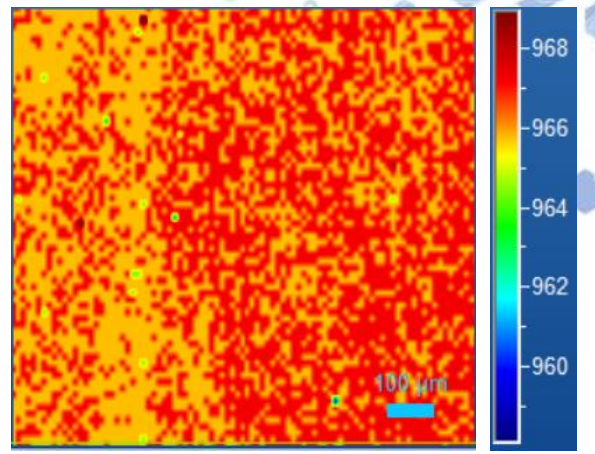
7,5 mW

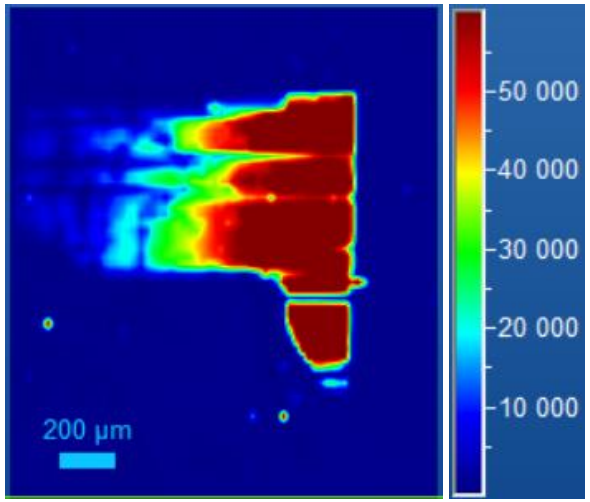
3,8 mW

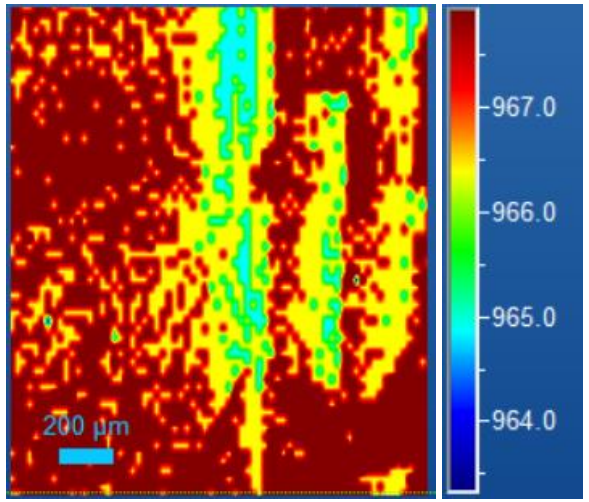


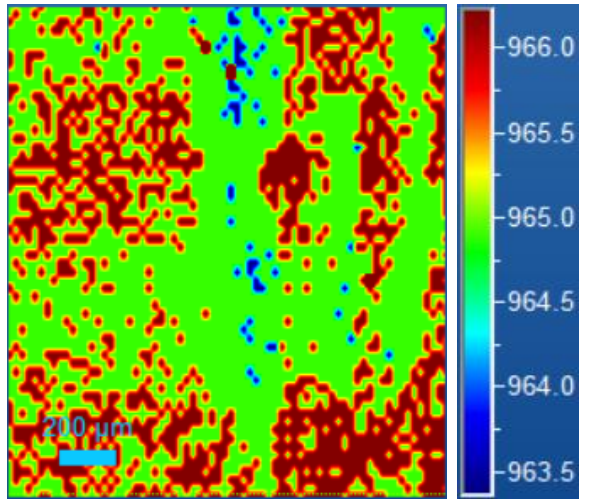


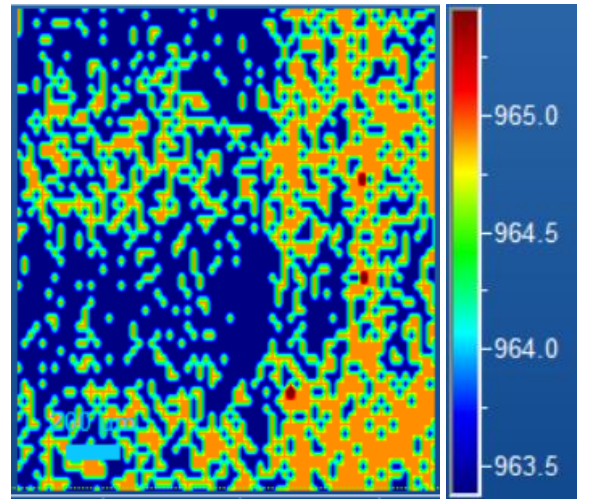












490 nm isolated

15 mW

7,5 mW

3,8 mW

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IMM

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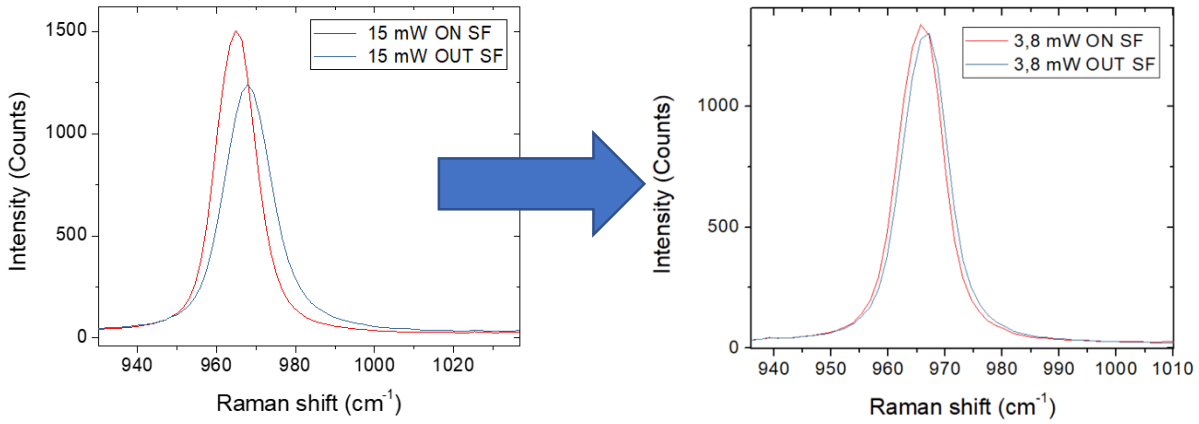
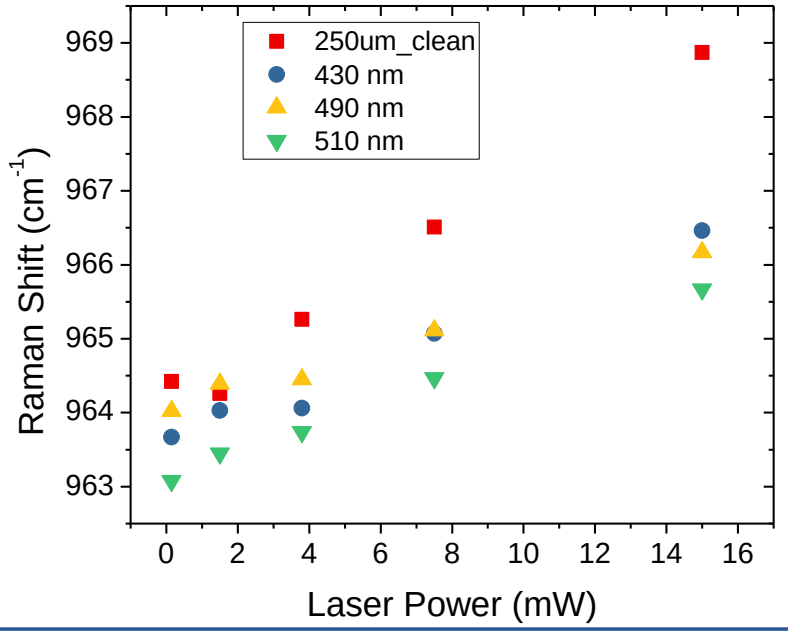
Defect Study

	15 mW		7,5 mW		3,8 mW		1,5 mW		0,15 mW	
Far SF	0,26 µs		0,32 µs		0,45 µs		0,98 µs		8,71 µs	
	On SF (µs)	Out SF (µs	On SF (µs)	Out SF (µs)	On SF (µs)	Out SF (µs)	On SF (µs)	Out SF (µs)	On SF (µs)	Out SF (µs)
430	0,18	0,21	0,23	0,25	0,31	0,32	0,68	0,68	5,41	5,41
490	0,14	0,23	0,17	0,27	0,23	0,29	0,49	0,49	3,46	3,46
510	0,15	0,22	0,17	0,25	0,24	0,30	0,48	0,55	4,43	4,43

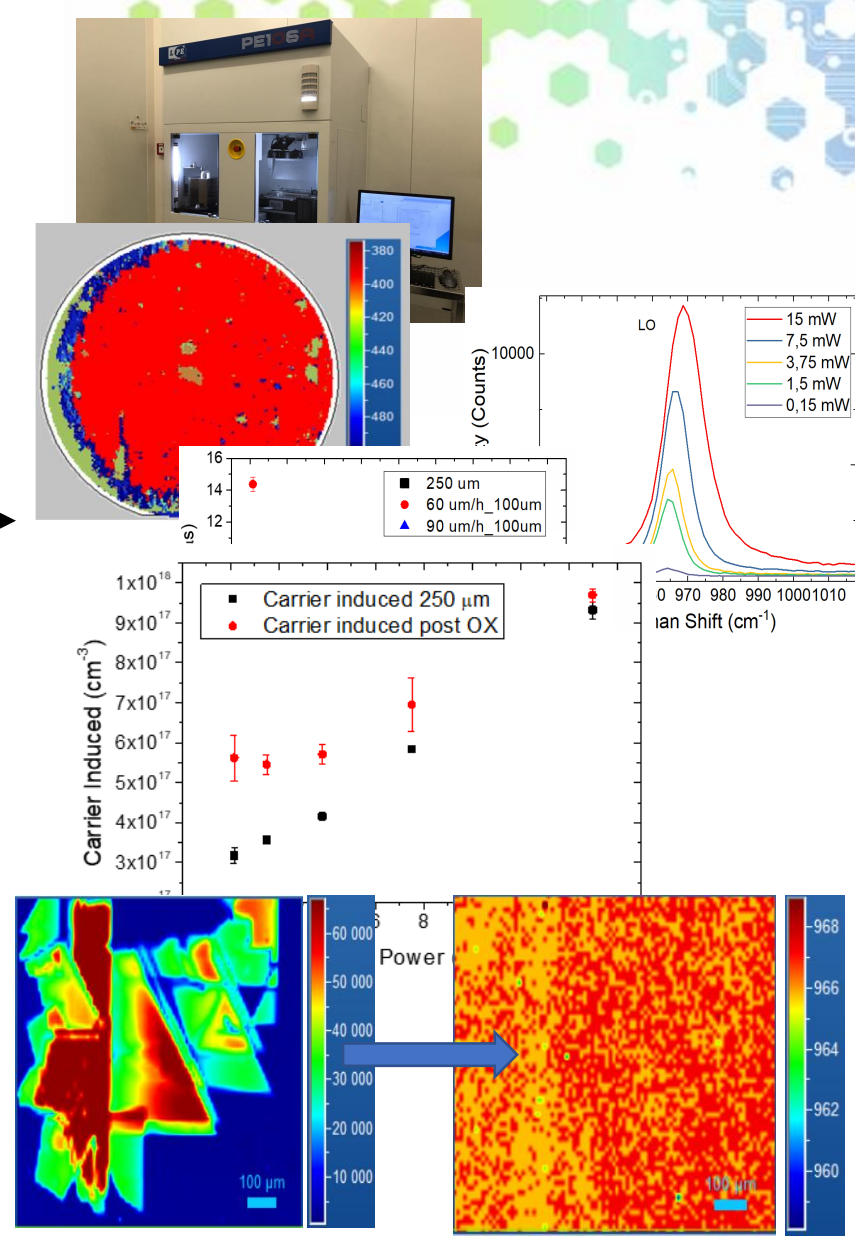
Clean AREA





Conclusion

- Study of the epitaxial growth process
- Carrier lifetime and carrier density evaluation
- Oxidation process 1400°C - 48h
- Influence of the defects on carrier lifetime



To be continued....

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